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Forest Land Use and Streamflow in Central Oregon

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THE SITUATION

As man's awareness and concern for his environment increase, the forest becomes more recognizable as a storehouse of vital renewable resources — water, wood, forage, recreation, and wildlife habitat. At the same time, in considering man's dependence on his environment, the need to manage these resources by the multiple use principle — in combinations that will best meet the needs of all the people — becomes more apparent. But the growing number of planning factors imposed by rapid change makes multiple use management increasingly complex. Now, more than at any previous time in conservation history, we need to understand how resources of the forest are influenced by planned management for given objectives. This paper considers the broad spectrum of management activities and the water-yielding characteristics of a small basin in central Oregon.

Perhaps nowhere in this rapidly changing Nation is change more readily apparent than in the Pacific Northwest. The situation is exemplified by Oregon's population which has spiraled from only 13,000 permanent settlers in 1850 to approximately 2,000,000 at present. Though half the present population lives in or near 20 principal commercial or industrial centers, and large volumes of water are withdrawn for domestic, industrial, and power production users, irrigation is the greatest consumptive use of water in Oregon (13). From simple diversions by early settlers, irrigation agriculture now extends to more than 1,500,000 acres. A

recent report by the Oregon State Water Resources Board (12) projects a population of 9,000,000 requiring irrigation of 13,700,000 acres 100 years from now.

In response to changes that have either taken place or are projected for the future, two trends are of special significance to forest land managers. These are:

1. Demands for water supplies to meet needs are increasing.
2. Demands for use and occupancy of forest lands for the other resources — wood, forage, recreation, and wildlife habitat — are also increasing.

Both trends are due to the same mounting pressures — expanding population and improving technology. Fortunately, through increasing general knowledge of the influence of land and vegetation treatments on hydrologic performance, we are beginning to understand that these increasing demands are not necessarily conflicting. Rather, there is an interacting character of good resource management which can be of benefit to watershed objectives. Except where prohibited by certain institutional arrangements for land management, such as National Parks and wilderness areas, management practices applied to other forest resources can gain reinforcement from their effect on water yield. This concept is reflected in recent activity of the U.S. Forest Service in bringing management to bear upon improvement of water yields on lands tributary to a water-short area (17).

WHAT IS UNDERSTOOD

General knowledge that vegetation and vegetation management can have a profound influence on streamflow has existed in this country for more than half a century. The earliest study of manipulation of forest vegetation in the United States was the Wagon Wheel Gap experiment begun in Colorado in 1910. In this joint Forest Service-Weather Bureau study, all vegetation was cut, windrowed, and burned on a 200-acre watershed in the headwaters of the Rio Grande River. Then a natural cover of aspen sprouts, grasses, and herbaceous plants was allowed to establish. During 7 posttreatment years, an annual increase of 0.96 inch, or 16 percent of the pretreatment yield, was attributed to removal of vegetation. Most of the increase was accounted for during the spring peak period (2).

A number of tests of forest treatment effects on water yields have been made since the Wagon Wheel Gap study designed to consider variations imposed by differing climate, soils, and vegetative types. These studies, ranging from North Carolina (10) and West Virginia (14) to Colorado (7) and California (15), have yielded the general result that streamflow increases when forest density is decreased. Also, this effect is soon followed by a trend toward original or pretreatment flow values if regrowth is allowed (11) (9). Bates (1), a pioneer in watershed management, likely had the results of his Wagon Wheel Gap study in mind when he wrote, in part:

Foresters, again and again, have pointed out the probability that a watershed bare of vegetation is capable of yielding a larger total quantity of water than the same watershed if covered with a forest, and the denser and more luxuriant the vegetation, the greater the loss of water to the watershed. This is a biological phenomenon no longer in need of proof.

Most investigators, however, see the role of forest vegetation as a paradox. Although there is evidence that forest stands can be modified to favor water yield, vegetation also plays a primary role in site stability and maintenance of water quality. Manipulations to reduce onsite water use should be applied only within limits which do not jeopardize the protective function.

Although studies of the relations between vegetation and water yields have provided intriguing prospects for resource management, there is feeling that the foundation is inadequate for widespread application (4). The scale of the tests has necessarily been limited, and not all regional variations have been touched upon. Broader scale tests or operational demonstrations on the effects of cover manipulation on water yield are needed.

THE CASE OF OCHOCO CREEK

In order to fix vegetation-streamflow relations on forest lands tributary to water-short areas of Washington and Oregon east of the Cascade Range, a number of experiments are being undertaken. Pending completion of these studies, it is possible to gain some insight on the effects of forest management activities by using available hydrologic data and forest use records. This case study has been made in order to evaluate the hydrologic performance of Ochoco Creek above Ochoco Reservoir (cover photo) in central Oregon in light of the use history of forested lands comprising the bulk of drainage area.

Study Area

Total drainage area tributary to Ochoco Reservoir, 6 miles east of Prineville, Oreg., is about 295 square miles, or 189,000 acres (see frontispiece). Elevations range from 3,100 feet at the reservoir to nearly 7,000 feet at the headwaters. Mean elevation is 4,600 feet. Generally, topography is gentle (fig. 1), with some rugged terrain at the uppermost reaches. Landscape features are strongly influenced by geologic formations present. A deeply fractured Clarno Formation, considered late Eocene or early Oligocene in age and lacustrine fluviatile in origin, predominates. The eastern or upper portion of the drainage is covered by the younger lavas of the Columbia River Formation, mid-Miocene fissure flows of fine-grained basalts, and andesites. A mantle of volcanic ash or loess of varying thickness and texture overlies both formations.

Soils reflect the normal influence of such environmental factors as elevation, exposure, vegetation, and position, as well as localized influences from clay beds or ash layers



Figure 1.--Downstream view of Mill Creek, tributary to Ochoco Creek.

found in the Clarno Formation. Most of the lower elevations are characterized by shallow soils on relatively steep slopes with occasional large rock outcrops. Deep, gravelly, medium-textured soils are found in the valley fill and narrow flood plain positions in major stream systems. Deposits of strong, medium-textured soils are found on alluvial fans that issue from side drainages and overlap the valley fill. At middle elevations, slopes become more complex and give rise to a variety of landforms including benches, valley fills, hummocky slump areas, and moderately steep colluvial slopes. Small areas of medium- to fine-textured valley fills are interspersed throughout the upper reaches.

Climate approximates Köppen's cool, snow-forest type (8) characterized by abundant sunshine, high evaporation, and wide daily and monthly temperature ranges. Mean annual temperature is 43° F. The coldest and warmest months, respectively, are January when temperatures frequently fall below 0° F. and July when temperatures occasionally exceed 100° F. Freezing can occur during any month, but mean frost-free season is about 60 days near 3,000 feet elevation. Frequently, under summer conditions, humidity will drop to 10 percent during the day. With 60 percent or more of possible sunshine, potential evaporation exceeds 36 inches annually.

Mean annual precipitation for the watershed is about 25 inches, ranging from 10 inches at lower elevations to nearly 50 inches in the highest reaches. Most precipitation falls during the October-June cool season, with about 50 percent occurring as snowfall. Mean monthly precipitation and air temperature at selected stations are summarized in table 1.

Approximately 75 percent of the drainage has forest cover consisting primarily of a ponderosa pine type (fig. 2), with minor amounts of associated species (Douglas-fir, white fir, and western larch) and lodgepole pine. A small amount of alpine fir is found at the highest elevation. Most of the mature forest types have an understory of young trees varying in density from a few to over 10,000 stems per acre.

An herbaceous ground cover composed mainly of grasses and sedges occurs under most timber canopies. Deep duff and litter are found only under very dense firs.

Nonforest types make up the remaining 25 percent. Sagebrush (*Artemisia tridentata*) is the dominant cover in scattered locations at the highest elevations, and juniper (*Juniperus occidentalis*) is prevalent at the lower elevations (5). Meadows, pastures, and irrigated farmlands occupy the valley fills.

Land Use History

Ochoco Reservoir, with a capacity of 47,500 acre-feet, was constructed primarily for irrigation purposes in 1920. The drainage area is 189,000 acres, of which 106,000 acres are administered by the Forest Service and 83,000 acres are in private ownership. Ochoco, Mill, and Marks Creeks are the major streams feeding the reservoir.

There are 52 established water rights, some dating back to the late 1800's, for irrigation of slightly more than 3,400 acres of land above the reservoir.¹ This acreage has remained essentially unchanged for many years, although rates and methods of water application may have varied among different landowners. The main irrigated crops are pasture, hay, and some small grain. The normal irrigation season, from April through August, requires about 4 acre-feet of water per acre.

There are no natural storage lakes in Ochoco Creek. Walton Lake, a manmade pond of about 20 surface acres near the headwaters, reached its present stage in 1958. Annual water retention to offset pond evaporation amounts to about 50 acre-feet.

One of the earliest uses of the watershed was mining for gold and cinnabar. Placer and hard-rock gold mining started around 1855, but mining operations since that time have been sporadic. About \$80,000 in gold was produced (6). There has been no recent gold mining activity. Cinnabar was discovered in 1899 in the vicinity of Lookout Mountain.

¹Personal communication with Mr. Joe Cox, local watermaster for Oregon State Engineer's Office, June 23, 1969.

Table 1.--Mean monthly precipitation and air temperature, Ochoco Creek Station

Month	Precipitation				Mean air temperature	
	Prineville	Ochoco Dam	Ochoco Ranger Station	Marks Creek Guard Station	Prineville	Ochoco Ranger Station
-----Inches----- --Degrees Fahrenheit--						
October	0.78	0.79	1.65	1.57	48.1	45.5
November	1.10	1.14	2.48	3.77	39.7	34.4
December	1.04	1.27	2.75	3.75	33.3	28.7
January	.99	1.12	2.19	3.10	31.0	24.3
February	.84	.85	1.75	2.20	35.5	29.5
March	.66	.84	1.60	2.49	40.0	34.4
April	.70	.65	1.31	1.88	46.0	41.6
May	1.09	1.47	1.71	1.76	52.2	48.6
June	.99	1.00	1.68	1.46	57.8	53.8
July	.30	.31	.58	.78	64.5	61.4
August	.31	.46	.60	.77	62.6	59.7
September	.57	.40	.75	.73	56.0	55.2
Annual	9.37	10.30	19.05	24.26	47.2	43.1

NOTE: Elevation in feet is as follows--Prineville, 2,868; Ochoco Dam, 3,057; Ochoco Ranger Station, 3,979; Marks Creek Guard Station, 4,600.



Figure 2.--Mature ponderosa pine typical of many stands on Ochoco Creek.

Mining since that time has been sporadic with some activity as recently as the late 1950's and early 1960's (3).

The earliest cinnabar mining was underground, but the more recent technique has been open pit mining. An area of about 20 acres of open strip mining work exists in the Lookout Mountain vicinity. Otherwise, there have been no significant land disturbances, clearings, or water use for mining since the construction of Ochoco Reservoir in 1920.

There has been recent prospecting for agates, jasper, and other semiprecious stones at scattered locations throughout the watershed. No significant land disturbances have resulted from this activity.

Grazing by cattle and sheep was another early use of the area. Unregulated grazing of large numbers was a common practice in the late 1800's and early 1900's. However, grazing records on National Forest land show grazing use by cattle or sheep to be quite stable since 1924, annually averaging about 933 and 3,100 animals, respectively. Normal season of use is from about June 1 to mid-September. Table 2 shows the permitted numbers of grazing stock on National Forest and certain private lands.

A resident mule deer population was estimated at 1,500 animals through 1950 and 5,000 in 1964. The watershed also supports a small, unestimated number of Rocky Mountain elk. Hunting is allowed and is one of the major recreational uses.

Other recreational use in the watershed is quite diversified. Fishing, "rock-hounding," camping, picnicking, sightseeing, hiking, and harvesting of forest products for pleasure are permitted and dispersed throughout the basin. Concentrated recreational use takes place mainly at Walton Lake Campground, Wildcat Campground, Ochoco Summit Campground, and White Rock Springs where formal facilities are established. Ochoco Reservoir is a very popular area for water-based recreation. Over 121,000 day visitors and 7,100 overnight campers used the facilities at Ochoco Lake State Park in 1967.

Timber harvesting, the major land use on Ochoco Creek, had a tentative beginning in the mid-1800's when early settlers cleared lands along the stream bottoms of Ochoco,

Marks, and Mill Creeks for farming. However, commercial harvest of timber did not start until about 1938 and then was principally limited to private land in the lower reaches of the watershed. From 1938 through 1945, almost 150 million board feet of timber was removed from about 25,000 acres of private land. This was a heavy cut, intended to remove 75 percent of the standing volume, yielding 2,900 to 7,700 board feet per acre. Beginning in 1947, cutting practice on private land became one of sanitation salvage, generally relogging to remove about 1,900 board feet per acre.

Commercial timber harvesting on National Forest land did not begin until 1942. By 1950, more than 100 million board feet of timber had been removed from 14,000 acres. Per-acre cut, designed to remove 65 percent of merchantable volume, ranged from 3,500 to 12,000 board feet. Since 1950, large areas have been salvage logged of high risk timber, but generally small per-acre volumes are removed. This salvage operation has relogged much of the cutover land.

In total, over 400 million board feet of timber was harvested from the Ochoco Reservoir watershed between 1938 and 1965. Cutting on both private and Federal lands has been concentrated in the mature ponderosa pine type. As data on volumes removed per acre indicate, cutting practices have varied from essentially complete removal of mature overstory to a very selective removal of scattered trees throughout the stand (fig. 3). Timber volumes removed from the watershed are summarized in table 3.



Figure 3.--Mature ponderosa pine stand after logging

Table 2.--*Grazing record in Ochoco area, 1924-65*(Animal months¹)

Year	Cattle	Sheep	Year	Cattle	Sheep
1924	4,442	--	1948	3,690	11,330
1929	3,800	1,188	1949	3,557	12,748
1930	3,700	6,500	1950	3,537	12,079
1931	3,600	6,500	1951	3,589	12,553
1932	3,500	6,500	1952	3,557	14,653
1933	3,400	6,500	1953	3,557	14,509
1934	3,300	6,500	1954	3,557	13,709
1935	3,200	17,834	1955	3,557	14,013
1936	3,100	6,500	1956	3,644	14,810
1937	1,200	6,500	1957	3,644	14,236
1938	2,897	6,500	1958	3,661	13,345
1939	2,560	6,500	1959	3,679	10,635
1940	2,392	19,413	1960	3,516	15,380
1941	2,461	9,658	1961	3,177	14,835
1942	2,435	9,265	1962	3,278	10,105
1943	2,249	9,265	1963	3,466	9,571
1944	1,985	9,265	1964	3,624	14,995
1945	2,050	10,974	1965	4,192	10,662
1946	3,690	--	Total	124,133	379,530
1947	3,690	--	Average	3,267	10,844

¹ Animal month = one mature cow with calf or one ewe with lamb for a month's tenure.

Because cutover areas either supported advance reproduction initially or reserve stands ensured regeneration, second-growth stands contained maximum numbers of vigorous stems (fig. 4). Beginning in 1955 on some of the areas first logged, a precommercial thinning program was initiated in dense ponderosa pine stands ranging from 2 to 8 inches in diameter. The thinnings, designed on the bases of site index and size class, have resulted in spacings of 10 to 14 feet between crop trees. A total of 1,410

acres were treated in this manner during the period 1955-65.

There are nearly 300 miles of roads, varying from two-lane asphalt highways to narrow, unsurfaced work roads in the watershed. Most, however, are rock-surfaced access roads (fig. 5) progressively built in connection with timber harvesting. It is estimated that these roads comprise a total of 500 to 600 acres of bare surface.

Table 3.--Annual timber harvest record, Ochoco Creek, 1938-65

Year	Cut Volume		Area logged		Average volume cut per acre	
	Private ¹	Forest Service	Private ¹	Forest Service	Private ¹	Forest Service
-- Thousand board feet-- ----- Acres----- ----- Board feet-----						
1938	18,500	0	2,400	0	7,700	--
1939	18,500	0	2,400	0	7,700	--
1940	18,500	0	2,400	0	7,700	--
1941	18,500	0	2,400	0	7,700	--
1942	18,500	2,711	3,240	220	5,700	12,300
1943	18,500	250	6,427	21	2,900	11,900
1944	18,500	708	3,593	59	5,140	12,000
1945	18,500	727	2,604	61	7,100	11,900
1946	2,000	7,964	453	664	4,410	12,000
1947	4,800	13,916	2,500	4,011	1,900	3,500
1948	4,800	12,460	2,500	1,577	1,900	7,900
1949	4,800	35,421	2,500	4,800	1,900	7,400
1950	4,800	27,228	2,500	3,230	1,900	8,400
1951	4,800	512	2,500	50	1,900	10,000
1952	4,800	2,803	2,500	9,080	1,900	300
1953	4,800	531	2,500	106	1,900	5,000
1954	4,800	3,661	2,500	8,500	1,900	430
1955	4,800	0	2,500	0	1,900	--
1956	4,800	488	2,500	6,100	1,900	80
1957	4,800	1,849	2,500	217	1,900	8,500
1958	4,800	11,544	2,500	17,240	1,900	660
1959	4,800	4,349	2,500	765	1,900	5,700
1960	4,800	9,384	2,500	13,795	1,900	680
1961	4,800	3,524	2,500	7,160	1,900	490
1962	4,800	462	2,500	400	1,900	1,150
1963	4,800	31,170	2,500	10,628	1,900	2,900
1964	4,800	20,805	2,500	8,647	1,900	2,400
1965	4,800	2,538	2,500	3,035	1,900	830
Total	241,200	195,004	73,417	100,366	3,290	5,270

¹ Annual data derived by averaging.



Figure 4.--Dense second-growth ponderosa pine.

There were no serious forest fires in the watershed during 1920-65. Most involved a quarter of an acre or less, and the largest recorded fire, only 85 acres. A review of the fire records shows damage has generally been minor. Fire history of the watershed is summarized below.

<u>Period</u>	<u>Total number of fires</u>	<u>Total acres burned</u>
1920-29	119	330
1930-39	119	119
1940-49	152	200
1950-59	52	19
1960-65	84	18
Total	526	686

Hydrologic Relations

The principal method of relating available precipitation and streamflow data for Ochoco Creek was the double-mass curve. In application, the graph of the cumulative data of one sequential variable plotted against the cumulative data of a related sequential variable is a straight line if the relation between the variables is fixed. If the relation changes



Figure 5.--Typical logging spur road. Disturbed areas are seeded to grasses.

during the plotted sequence, due either to a change in data collecting techniques or to some physical change, a break or change in slope will appear. Statistical tests for significance of apparent slope breaks can be made (16).

Precipitation-Runoff Relations

Precipitation stations within or closely adjacent to the Ochoco Creek basin, with periods of records long enough to be useful in analysis, are at Prineville, Oreg. (1897 to present) and Ochoco Ranger Station (1936 to present). Annual precipitation amounts recorded at these locations appear in table 4.

Ochoco Reservoir, essentially containing the outflow of Ochoco Creek, has been in continuous operation by the Ochoco Irrigation District since 1920. Records of reservoir level, flow in irrigation feed canals, and flow of Ochoco Creek below the reservoir are convertible to reservoir inflow. Annual inflows for water years² 1922-65 are shown in table 4.

The first step in analysis of Ochoco Creek hydrologic data was to check the consistency of precipitation records at Prineville and Ochoco Ranger Stations. A double-mass plot (fig. 6) of the annual precipitation report of these two stations shows a distinct slope break at the water year 1957. The double-mass plotting of each of these stations individually against a third station, nearby but outside the Ochoco drainage, determined that the slope break was attributable to a change at the Prineville station. Subsequent inquiry disclosed that about 1956 the Prineville station was moved nearly 3 miles to a new Weather Bureau cooperator location. The curve in figure 6 was used to adjust Prineville precipitation data subsequent to 1956 to make it consistent with prior records.

Precipitation at both stations and Ochoco Reservoir inflow were then related by use of

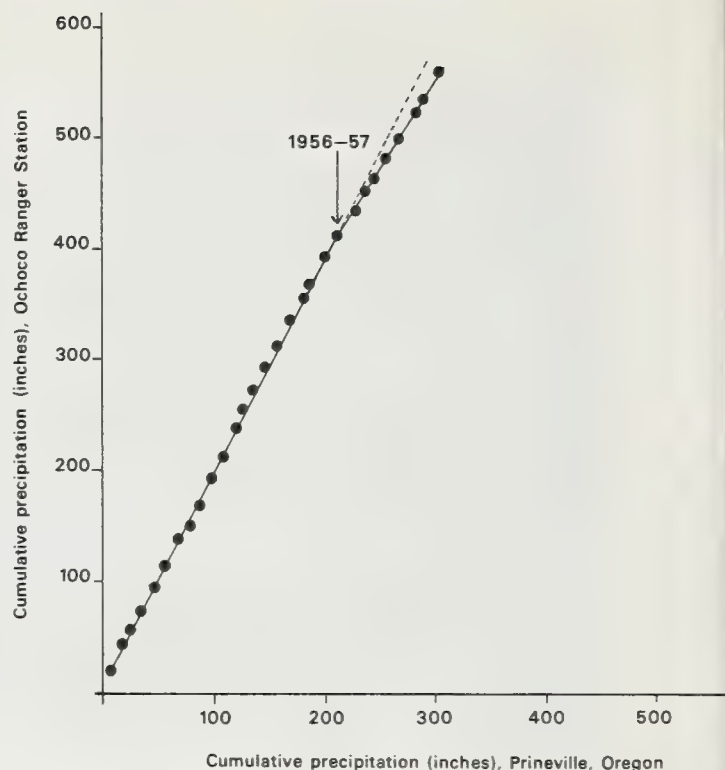


Figure 6.--Double-mass curve of precipitation data.

double-mass plots (figs. 7 and 8). Because the relation between precipitation and streamflow is seldom a constant ratio, these curves are not intended for analysis. Rather, they are useful only if we look at trends or possible changes in precipitation-runoff relations for further analysis.

Figure 7, the double-mass plot of Prineville precipitation and Ochoco Reservoir inflow, shows two distinct slope breaks which suggest changes in precipitation-streamflow relations. The first is a sharp break at water year 1942. The second and less distinct break occurred at water year 1956.

Figure 8, relating precipitation at Ochoco Ranger Station to reservoir inflow, also shows a distinct break at water year 1942 and a less distinct break at water year 1957.

²In this report, a water year begins October 1 and ends September 30. Numerical designation is the calendar year in which the water year ends.

Table 4.--*Annual precipitation amounts, Prineville and Ochoco Ranger Station, and Ochoco Reservoir inflow, 1922-65*

(Inches)

Water year	Precipitation		Inflow, Ochoco Reservoir
	Prineville	Ochoco Ranger Station	
1922	8.63	--	2.84
1923	11.85	--	2.57
1924	7.98	--	0.89
1925	11.48	--	2.89
1926	7.59	--	.87
1927	8.38	--	3.24
1928	6.98	--	2.83
1929	4.49	--	.46
1930	8.60	--	.28
1931	6.84	--	.40
1932	7.75	--	2.37
1933	7.07	--	1.45
1934	9.11	--	.17
1935	8.26	--	1.15
1936	11.13	--	1.61
1937	8.98	20.50	1.72
1938	10.31	22.96	3.55
1939	4.98	14.29	.83
1940	10.76	15.17	1.59
1941	11.16	21.02	1.21
1942	11.23	18.53	3.24
1943	12.31	25.39	6.29
1944	10.31	12.32	.70
1945	9.19	18.94	2.62
1946	9.90	23.15	6.77
1947	9.34	19.75	1.42
1948	12.55	¹ 26.16	5.88
1949	5.91	¹ 15.40	4.15
1950	8.15	17.66	¹ 4.26
1951	11.08	¹ 20.70	5.93
1952	12.00	20.12	4.57
1953	11.89	23.91	4.12
1954	11.20	19.21	3.22
1955	5.08	14.11	1.09
1956	14.16	24.14	6.08
1957	11.37	17.39	¹ 3.24
1958	16.28	25.40	5.46
1959	8.11	14.63	1.15
1960	7.72	13.33	1.44
1961	11.82	17.52	2.37
1962	11.84	18.21	3.39
1963	13.73	20.72	3.18
1964	7.69	14.73	1.46
1965	14.68	24.34	5.77

¹Estimated in part.

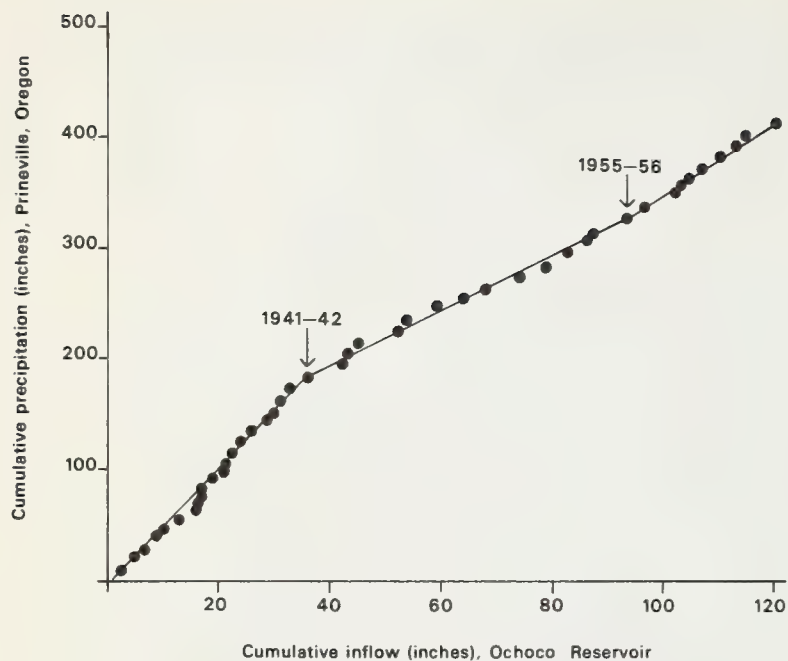


Figure 7.--Double-mass curve of precipitation and reservoir inflow.

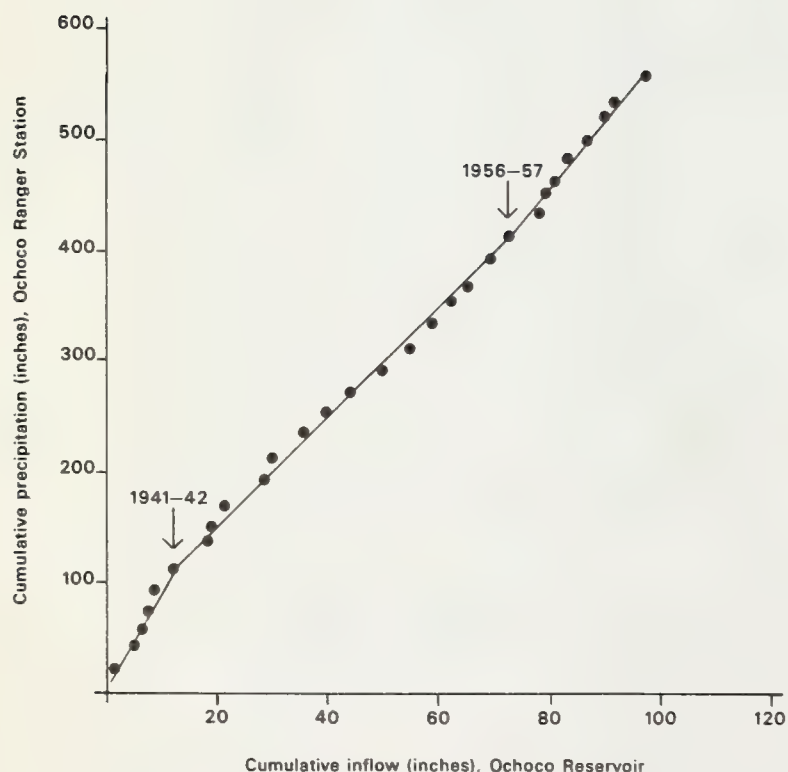


Figure 8.--Double-mass curve of precipitation and reservoir inflow.

Double-Mass Analysis

An analysis relating precipitation at Ochoco Ranger Station to Ochoco Reservoir inflow would be desirable, because that station is located near the center of the basin. However, since precipitation records prior to 1937 are not available, it became necessary to use the longer Prineville precipitation records in the analysis.

When the double-mass curve is used in an analysis of precipitation-runoff relations or streamflow trends, the cumulative measured flow should be plotted against a cumulative computed or pattern flow based on some determined precipitation-runoff relation. A variable ratio between precipitation and streamflow violates the theory of double-mass analysis.

A means for computing pattern inflow at Ochoco Reservoir was developed by relating cumulative annual precipitation at Prineville to cumulative annual reservoir inflow for water years 1922 to 1942 (see fig. 7) through a least squares fit linear regression.³ This regression equation was then used in computing cumulative pattern inflow for each water year from 1922 to 1965.

Figure 9 is the resulting double-mass plot of computed pattern inflow against measured inflow into Ochoco Reservoir.

A number of year-to-year breaks are evident in figure 9. However, most users of double-mass curves recognize that short-term changes can be due to chance and generally choose to ignore breaks persisting for less than 5 years. Two distinct slope breaks persisting for more than 5 years are identifiable at water years 1942 and 1958. The first, indicating increased flow during water years 1942 to 1958, represents a departure from pattern flow of +2.21 inches per year. During the period 1958 to 1965, the departure from pattern flow amounted to +1.03 inches per year.

$$^3 \hat{y} = 2.27 + 0.1826X; r = 0.994$$

where X = cumulative precipitation, in inches, at Prineville, Oreg.

\hat{y} = estimated cumulative inflow in inches.

To determine whether the apparent slope breaks in figure 9 occurred by chance, statistical tests of significance were made by methods of covariance. The periods 1942-58 and 1958-65 were tested against the period 1921-42. Differences were found to be highly significant⁴ in both cases. The difference between the 1942-58 and the 1958-65 periods was found to be significant at the 95-percent confidence level.

These statistical tests show that increased streamflow subsequent to 1942 did not occur due to chance. They show further that the 1.18 inches average decrease in annual flow after 1958 is a real change.

The recognized slope breaks indicate times at which inconsistencies or changes occurred in the relation between pattern and measured flows. The difference in slopes of the lines on either side of the breaks indicates the extent of the change. With reasonable assurance that data collection methods have not changed, the need remains to identify plausible events or physical changes which coincide with slope breaks. Knowing the approximate timing of changes in streamflow relationships, one may analyze the history of Ochoco Creek for causes. However, such analysis is necessarily qualitative due to the general character of certain use data.

The possibility exists that streamflow relations changed in response to a persistent climatic change. Though annual precipitation amounts at Prineville during the period 1922-65 are essentially a normal distribution, mean annual precipitation during 1943-58 was nearly 2 inches greater than during 1922-42. However, from prediction equations developed for both periods,⁵ a streamflow increase of only 0.5 to 0.7 inch would be the expected result of a 2-inch increase in annual precipitation.

⁴Significant at the 99-percent confidence level.

⁵ $\hat{y} = 0.24X - 0.38$; $r = 0.48$
 $\hat{y} = 0.36X + 0.27$; $r = 0.52$
 where X = annual precipitation, in inches, at Prineville, Oreg.
 \hat{y} = estimated annual inflow, in inches, at Ochoco Reservoir.

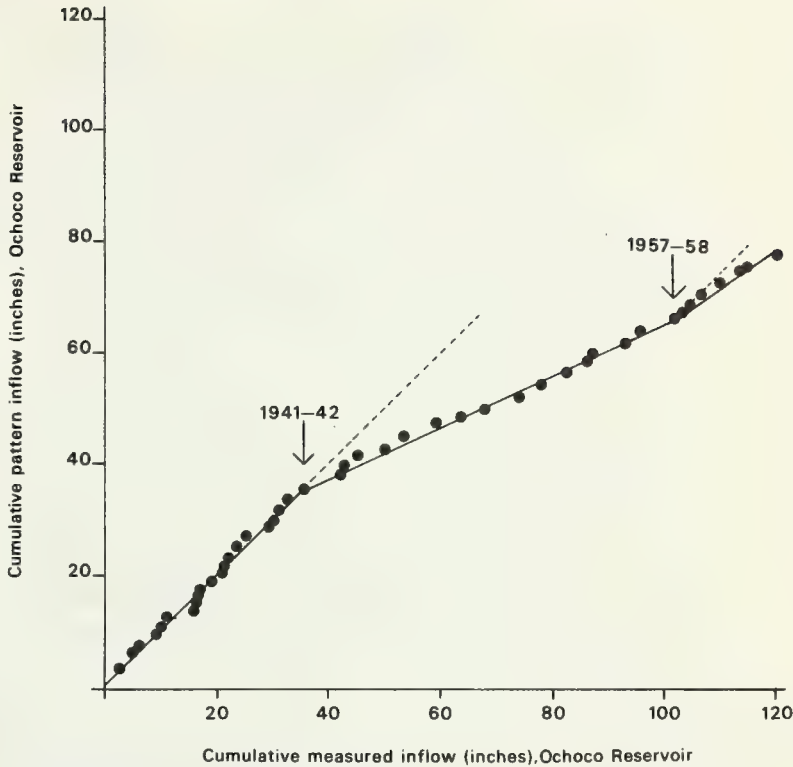


Figure 9.--Double-mass curve of measured and pattern inflow.

Certain land use activities, such as diversions for irrigation agriculture above the reservoir and for forest grazing, have been essentially stable throughout the period studied. Consequently, they provide no logical explanation for streamflow changes. Other uses, such as recreation and mining, either alter the landscape very little or occupy such minute portions of the basin that they also fail to suggest causes for major changes in hydrologic response. Similarly, fires have been but minor events in land use history.

Timber harvest is the only recorded major land use on Ochoco Creek which might conceivably result in a significant change in water yield. And intensification of timber harvest activity, beginning in 1938 and peaking in 1949, is approximately coincident with the first break identified in the double-mass curve (fig. 9).

The slope break occurring about water year 1958, manifested as a streamflow decrease of 1.18 inches per year, does not coincide with any particular recorded activity. It may represent a trend toward original flow values, similar to trends observed in water yield experiments dealing with forest cutting. Commercial timber harvest during 1938-49 removed high per-acre volumes from mature stands. Dense second-growth stands resulting from this heavy cutting now fully occupy most of these sites. Since 1951, timber harvesting generally has been on a sanitation salvage basis removing low per-acre volumes. These two factors — full stocking of older cutover by dense second growth, and general reduction of timber harvest — could conceivably combine in higher transpiration draft, thus decreasing water yield.

Sedimentation

There are no formal records of sedimentation in Ochoco Reservoir. The manager of the Ochoco Irrigation District, a longtime resident of the area, believes that in the past 45 years the reservoir capacity has been reduced 250 to 500 acre-feet by sediment. He further believes that most of this sediment is the result of two major December-January floods in 1945-46 and 1964-65. No reservoir management or irrigation problems have resulted from either suspended or deposited sediments.⁶

SUMMARY

The prosperity of the West greatly depends on adequacy of water supplies. Though much water use is at considerable distance from the forest, forest lands are intimately related to western irrigation in that they are the origin of perhaps 85 percent of the water. In central Oregon, water will probably fix the upper limits of population and living standards.

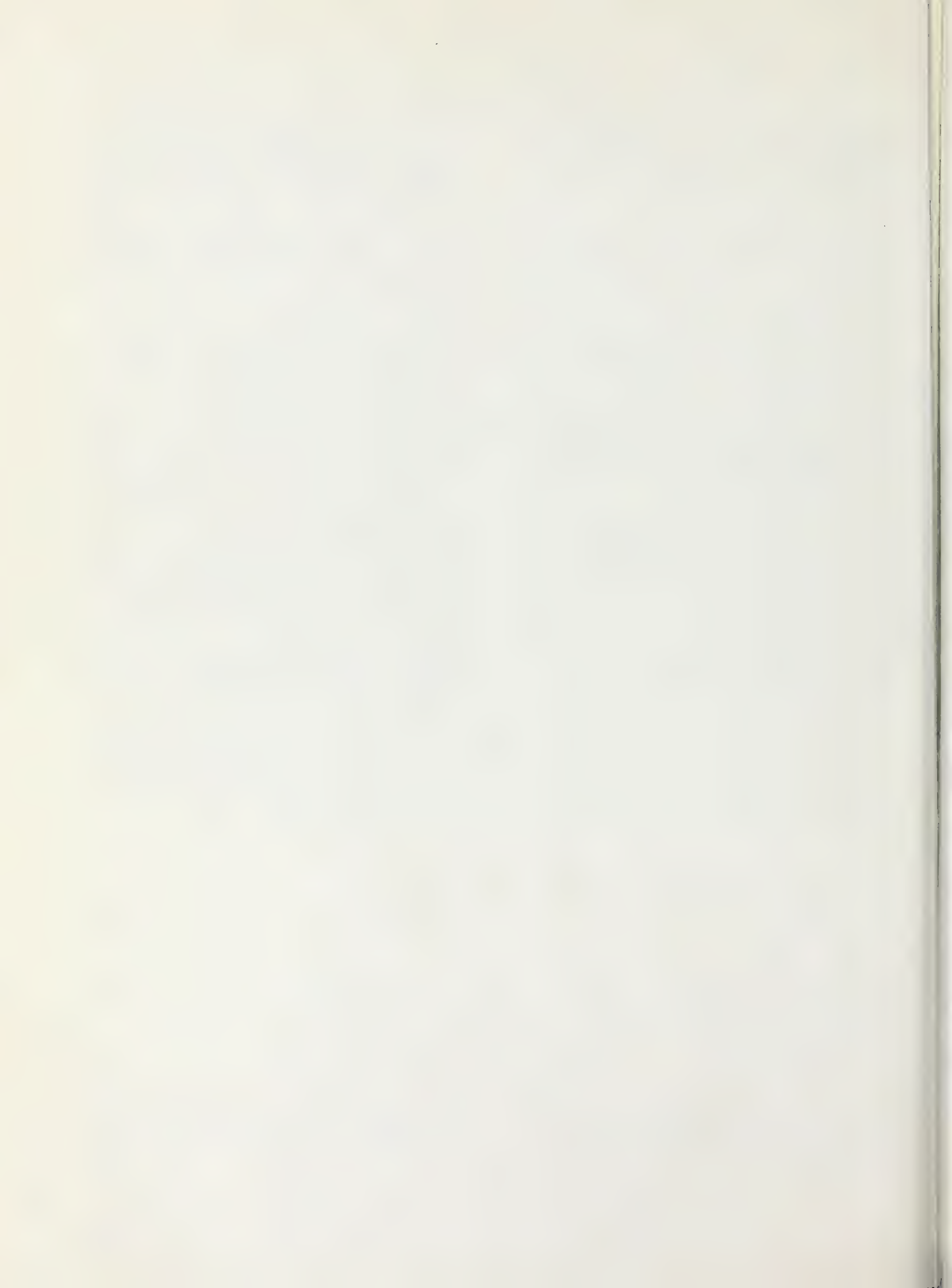
In this case study, the hydrologic performance of a 295-square mile drainage in central Oregon was compared with the land use history for the period 1921-65. Two distinct changes in streamflow regimen were identified. The first, beginning about water year 1942, was an increase of 2.21 inches in average annual yield. The timing of this increase is approximately coincident with the onset of timber harvesting activity in the basin. The second change was a decrease of 1.18 inches in average water yield beginning about 1958. This change could possibly be related to the full stocking of cutover lands by dense, second-growth stands and a general reduction of timber harvest activity.

Though more sensitive, refined tests of the influence of timber harvest on water yield are needed for stands east of the Cascade Range, the analyses in this report show that accepted management practices for vegetative types found on Ochoco Creek have favored water yields.

⁶Personal communication, Mr. LaSelle E. Coles, Ochoco Irrigation District Manager, Prineville, Oreg., June 23, 1969.

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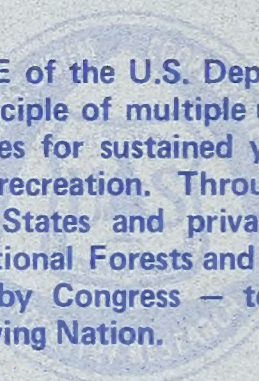
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